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Errata to Crisis Stability Indices for Adaptive Two-Layer Defenses

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Errata to Crisis Stability Indices for Adaptive Two-Layer Defenses

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ERRATA TO CRISIS STABILITY INDICES FOR ADAPTIVE TWO-LAYER DEFENSES

by

Gregory H. Canavan

ABSTRACT

An earlier treatment overestimated the survivability of an attacker's non-alert aircraft and hence their contribution to his first strike. This report corrects the error and discusses its impact, which is primarily important for ground-based defenses. It reduces the attacker's aircraft survival rates to about those of the defender's, improving the stability properties of space-based defenses.

I. INTRODUCTION

"Crisis Stability Indices for Adaptive Two-Layer Defenses" discusses crisis stability indices for two-sided exchanges between symmetrical offensive and defensive forces.[1] The survivability of non-alert aircraft plays an important role in determining those indices. Its treatment of the attacker's non-alert aircraft is in error. It overestimates their survivability and hence their contribution to the first strike. This report gives the correct formulation of their survivability and discusses the figures of the earlier report that are affected. Only four are affected significantly, but they lead to a different assessment of the relative impact of small boost-phase and preferential defenses on stability.

II. SURVIVABILITY CHANGES

The previous report gives the fraction of the defender's non-alert aircraft surviving as[2]

$$\epsilon \approx [\theta hI/ypmM]^{0.9 \cdot p\hat{}0.64} \cdot [(1-\theta)hI/yqnN]^{0.9 \cdot q\hat{}0.64}, \qquad (1)$$

where the two terms in brackets correspond to survival against land and submarine missile re-entry vehicles (ICBM and SLBM RVs), respectively. In the first term, h is the fraction of the I interceptors that is allocated to defending airbases, and y is the fraction of M ICBMs with m RVs each allocated to attacking airbases, of which a fraction p penetrates the attacker's boost phase defenses.[3] The parameter

$$\theta = 1/[1 + (q/p)^{0.64}] \qquad (2)$$

is the allocation of the interceptors between ICBM and SLBM RVs that maximizes ϵ. In the second term N is the number of SLBMs with n RVs each. The exponents are fits to numerical solutions for the survival due to random removal of missiles by boost-phase defenses and preferential removal of RVs by a downstream layer.

The survival of the attacker's non-alert aircraft, ϵ', is given by Eq. (1), with modifications. The SLBM portion is the same, but only a fraction $\approx \epsilon$ of the defender's missiles survive the first strike. Because of their reduced number, they do not penetrate the attacker's boost-phase defense as well as the first strike ICBMs. The attacking ICBM penetration probability is

$$p \approx e^{-fK/M}, \qquad (3)$$

where K is the number of boost-phase, space-based interceptors, and f is a constant, which is about 0.13 for current missile basing. Of the defender's M ICBMs, about $\epsilon \cdot M$ survive the first strike, so their penetration probability is only

$$r \approx e^{-fK/\epsilon M} = p^{1/\epsilon}. \qquad (4)$$

The overall survival and penetration probability of the defender's ICBMs is $\approx \epsilon \cdot r$. Thus, the ICBM part of ϵ' is

$$\epsilon_{IC}' \approx [\theta hI/y\epsilon rmM]^{0.9 \cdot \epsilon r\hat{}0.64}. \qquad (5)$$

In the previous report only this part was used for ϵ'. Because $\epsilon \approx 0$, that gave $\epsilon' \approx 1$. The SLBM attrition of the attacker's non-

alert aircraft, which is larger, was omitted. Its inclusion makes significant corrections for small I, as discussed below.

III. RESULTS

Correcting the attacker's non-alert aircraft survivability makes significant changes in four of the figures of the previous report. A complete set of corrected figures are attached, using the numbering of the original report, although only those that change significantly are discussed explicitly below.

A. First Strike

Figure 3 gives the magnitude of the first strikes as a function of the number of space-based interceptors, K, for I = 0, 500, 1000, and 2000 preferential interceptors. The original curves had maxima at K = 0; the corrected curves for I = 500, 1000, and 2000 interceptors still have weak maxima at 4000, 2000, and 500 interceptors, respectively.

The curve for I = 0 changes more. Rather than having a maximum, it has a minimum at $K \approx 2{,}000$. At small K the main contribution to the first strike on value is from missiles. At large K the dominant contribution is from aircraft. At $K \approx 2{,}000$ the missiles are attrited by about a factor of three, but the survivability of the non-alert aircraft has not yet increased significantly, according to the curves discussed in the next section. The resulting minimum produces a minimum in the second strike cost discussed later.

B. Non-Alert Attack Aircraft Survival

Adding SLBM restrikes on the attacker's non-alert aircraft reduces the survival rates of Fig. 11 significantly from those of the corresponding figure of the original report. The modified non-alert aircraft survival rates are similar to the defender's non-alert aircraft survival rates of "Crisis Stability" Fig. 4.[4]

C. Second Strike Costs

Adding SLBM restrikes alters the shape of the second strike costs of Fig. 13 for I = 500, 1000, and 2000, but changes their magnitudes little. However, the cost for I = 0 changes from having a maximum to having a minimum because of the minimum in the first strike discussed in III A. The second strike cost is

$$C_2 = 1 - e^{-R_1/V} + L \cdot e^{-R_2/V}, \qquad (6)$$

where R_1 and R_2 are the magnitudes of the first and second strikes and V is the number of military value targets on each side. For intermediate K, adding SLBM restrikes decreases R_1 but leaves R_2 unchanged. The change in C_2 is[5]

$$dC_2 = (e^{-R_1/V}/V)\,dR_1, \qquad (7)$$

so that a dR_1 large and negative gives a dC_2 large and negative.

D. Stability Indices

Adding SLBM restrikes has little impact on the crisis stability indices for I = 500, 1000, and 2000, but the change for I = 0 is significant. Whereas on the original figure the curve for I = 0 fell faster and further than those for I > 0, the modified curve is relatively flat out to K = 2,000. The reason for that can be illustrated. The curve for C_1 is[6]

$$C_1 = 1 - e^{-R_2/V} + L \cdot e^{-R_1/V}. \qquad (8)$$

The changes are primarily in R_1, so

$$dC_1 \approx -(L/V)\,e^{-R_1/V}dR_1. \qquad (9)$$

Thus, a negative dR_1 gives a positive but smaller dC_1. The net impact on the stability Index $\equiv C_2/C_1$ is

$$d(\text{Index}) \approx dC_2 - (C_2/C_1)\,dC_1 \approx e^{-R_1/V}(1 - L/2)\,dR_1/V. \qquad (10)$$

For K = 2,000, $dR_1 \approx 3{,}000$; thus, for the V = 2,000 and L = 1/3 used here and in the original,

$$d(\text{Index}) \approx e^{-1.5}(1 - 1/6) \cdot 1.5 \approx 0.3, \qquad (11)$$

which is roughly the change seen from the original 0.55 index to the 0.86 index of the modified Fig. 14.

In the original analysis many of the attacker's non-alert aircraft were incorrectly allowed to contribute to the first strike. That significantly increased the cost of waiting to strike second, and hence reduced the stability index. In the

modified analysis the non-alert attack aircraft do not contribute until $K > 2,000$. Thus, aircraft do not contribute strongly until missiles are attrited strongly, and the resulting index is relatively flat.

E. Interpretation

In the earlier report stability indices fell rapidly with increasing K for $I = 0$, suggesting that boost-phase defenses were destabilizing and should not be deployed without preferential defenses. The modified results above indicate that boost-phase defenses are the more stabilizing of the two, and that deploying preferential defenses without boost-phase defenses would reduce stability by 10-15%.

Boost-phase defenses alone would not, however, increase indices above current levels. For the range of defenses studied above, boost-phase defenses would keep stability indices constant through moderate defenses and would cause a slight decline thereafter. Inspection of the modified Fig. 14 indicates that deploying boost-phase defenses first and then switching to combinations of defenses at (I,K) = (2,000, 1,000), (1,000, 2,000), or (500, 2,500) would place the defenses on stable trajectories without ever decreasing indices. Those combinations could then increase stability through the addition of defenses in the mixes indicated.

IV. RELATIONSHIP TO EARLIER ANALYSES

The corrected figures here compare closely to the corresponding figures of "Analytic Optimizations in Crisis Stability,"[7] which was done earlier than "Crisis Stability" and without the error in the SLBM restrike on non-alert attack aircraft. That favorable comparison means that the analytic approximation to aircraft survivability used there,

$$\epsilon'' \approx 1 - \exp[-hI/y(mM + nN), \qquad (12)$$

which is more useful for analytic estimates, is valid for relevant conditions. It also implies that the asymptotic stability results[8] that were obtained with that approximation

apply to adaptive preferential defenses as well. Those results are all that is necessary to establish the increase of stability with increasing defensive or decreasing offensive forces.

V. SUMMARY AND CONCLUSIONS

The earlier treatment of attack non-alert aircraft overestimated their survivability and their contribution to the first strike. It included only the ICBM contribution to the restrike on attack nonalert aircraft, omitting the SLBM contribution, which is larger. This report gives the correct formulation and discusses its impact.

Adding SLBM restrikes affects first strikes significantly only for $I = 0$. It produces a minimum rather than a maximum, and reduces the attacker's non-alert aircraft survival rates to about those of the defender. That produces a minimum rather than a maximum in second strike costs, which causes the crisis stability index to be larger and flatten out to about 2,000 boost-phase defenders. In contrast to the earlier report, this result suggests that space-based interceptors are more stabilizing than downstream ones and hence should be deployed earlier.

REFERENCES

1. G. Canavan, "Crisis Stability Indices for Adaptive Two-Layer Defenses," F. Kane, Ed., Proceedings Crisis and Arms Control Stability Meeting (Operations Research Society of America/TIMS: Anaheim, California, 5 November 1991) [Los Alamos National Laboratory report LA-11974-MS, March 1991].

2. G. Canavan, "Crisis Stability," op. cit., p. 8, Eq. (9).

3. G. Canavan, "Crisis Stability," op. cit., p. 3, Eq. (2).

4. G. Canavan, "Crisis Stability," op. cit., Fig. 4.

5. G. Canavan, "Crisis Stability," op. cit., p. 12, Eq. (15).

6. G. Canavan, "Crisis Stability," op. cit., p. 12, Eq. (16).

7. G. Canavan, "Analytic Optimizations in Crisis Stability," Los Alamos National Laboratory report LA-11959-MS, March 1991.

8. G. Canavan, "Analytic Optimizations in Crisis Stability," op. cit., pp. 12-4.

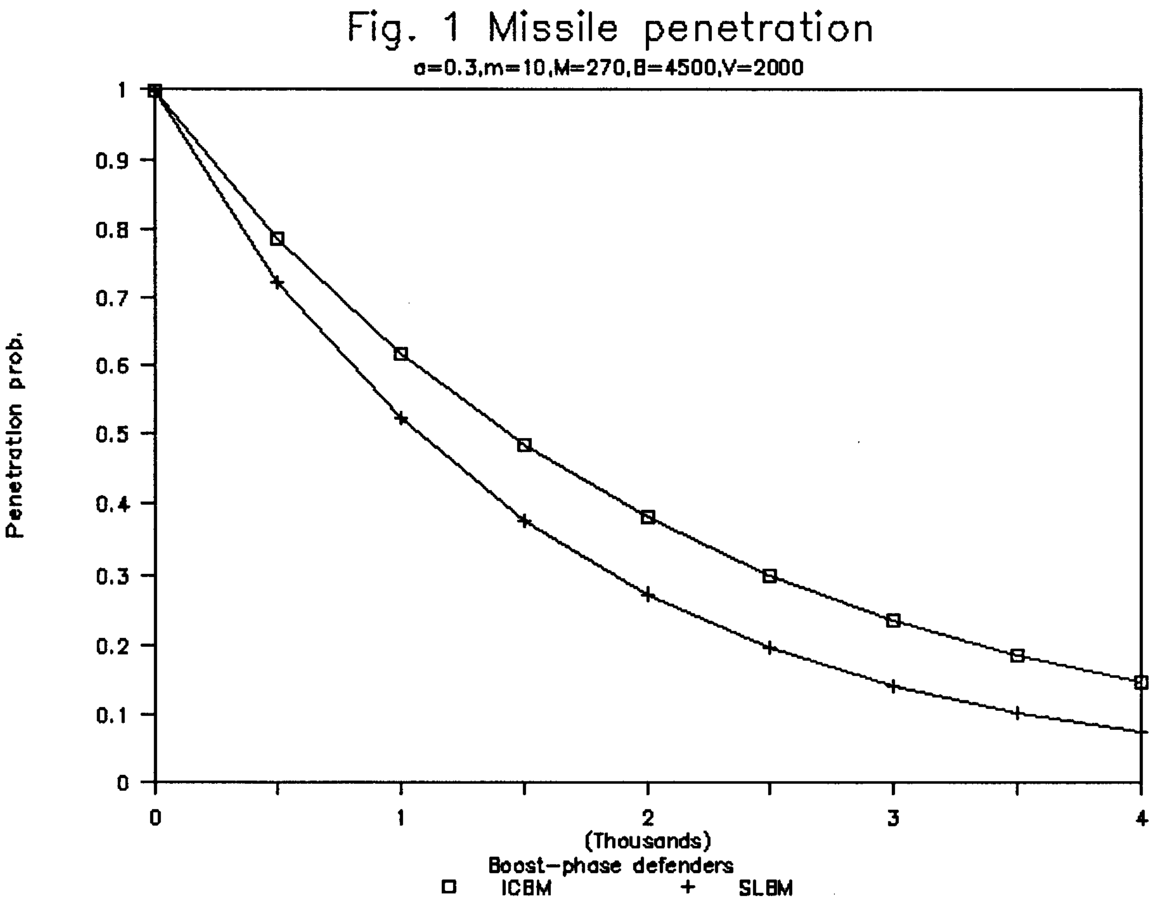


Fig. 1 Missile penetration
a=0.3,m=10,M=270,B=4500,V=2000
Penetration prob.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
(Thousands)
Boost-phase defenders
ICBM
SLBM

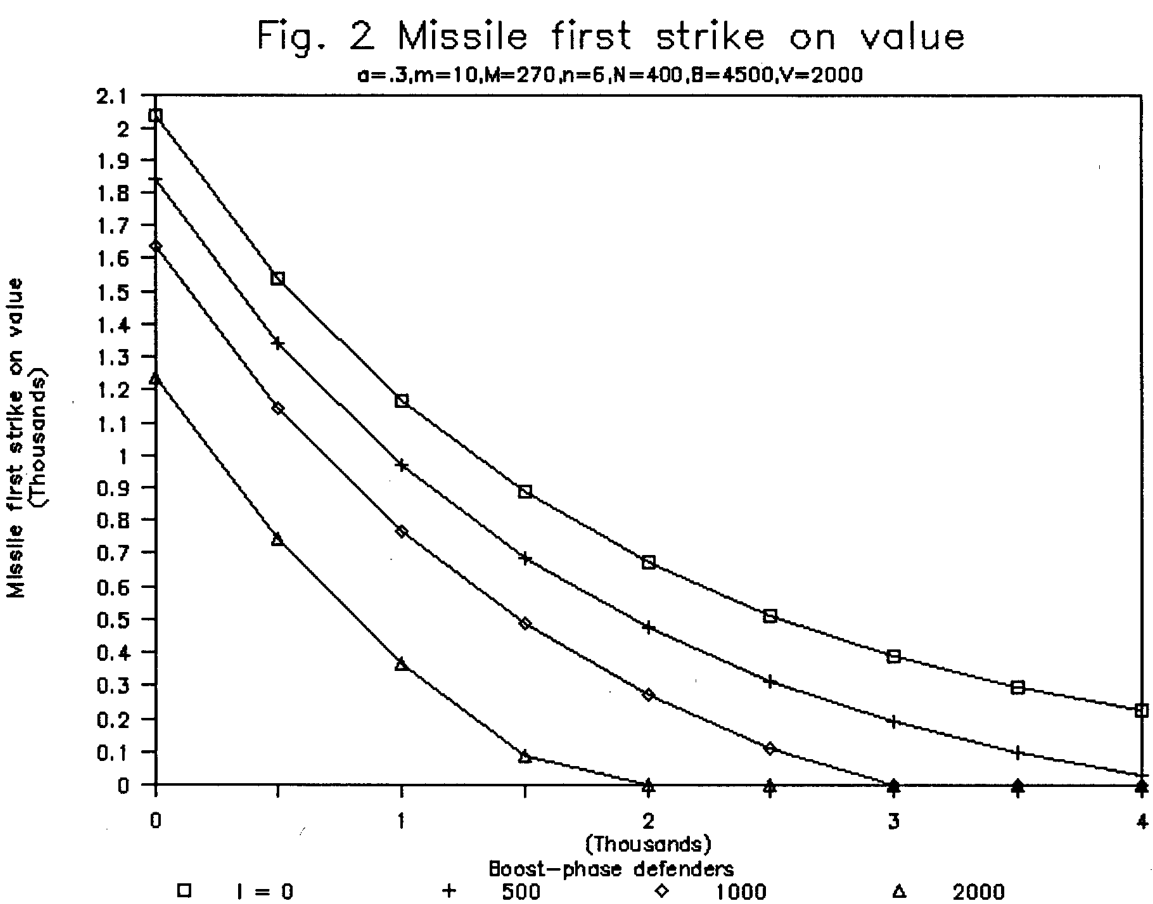


Fig. 2 Missile first strike on value
a=.3,m=10,M=270,n=6,N=400,B=4500,V=2000
Missile first strike on value (Thousands)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
(Thousands)
Boost-phase defenders
I = 0
500
1000
2000

Fig. 3 First strike on value

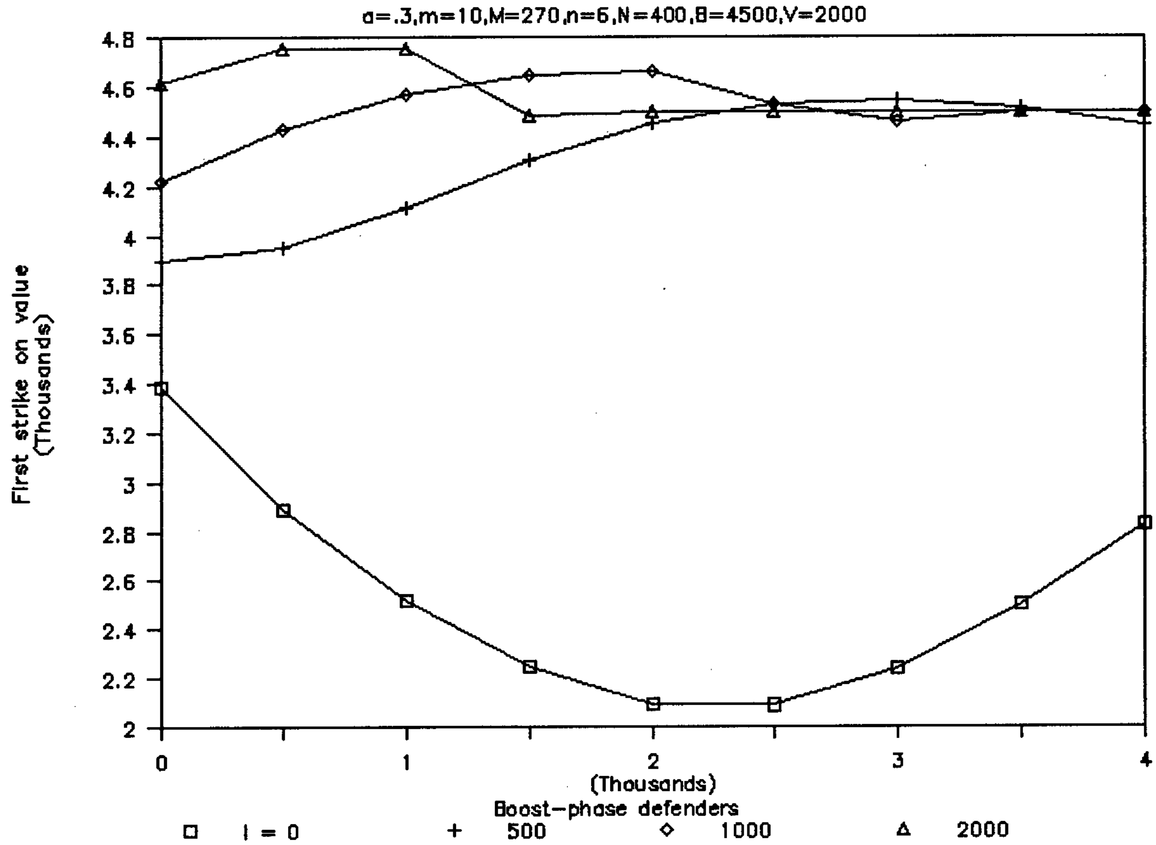


Fig. 4 Aircraft survival probability

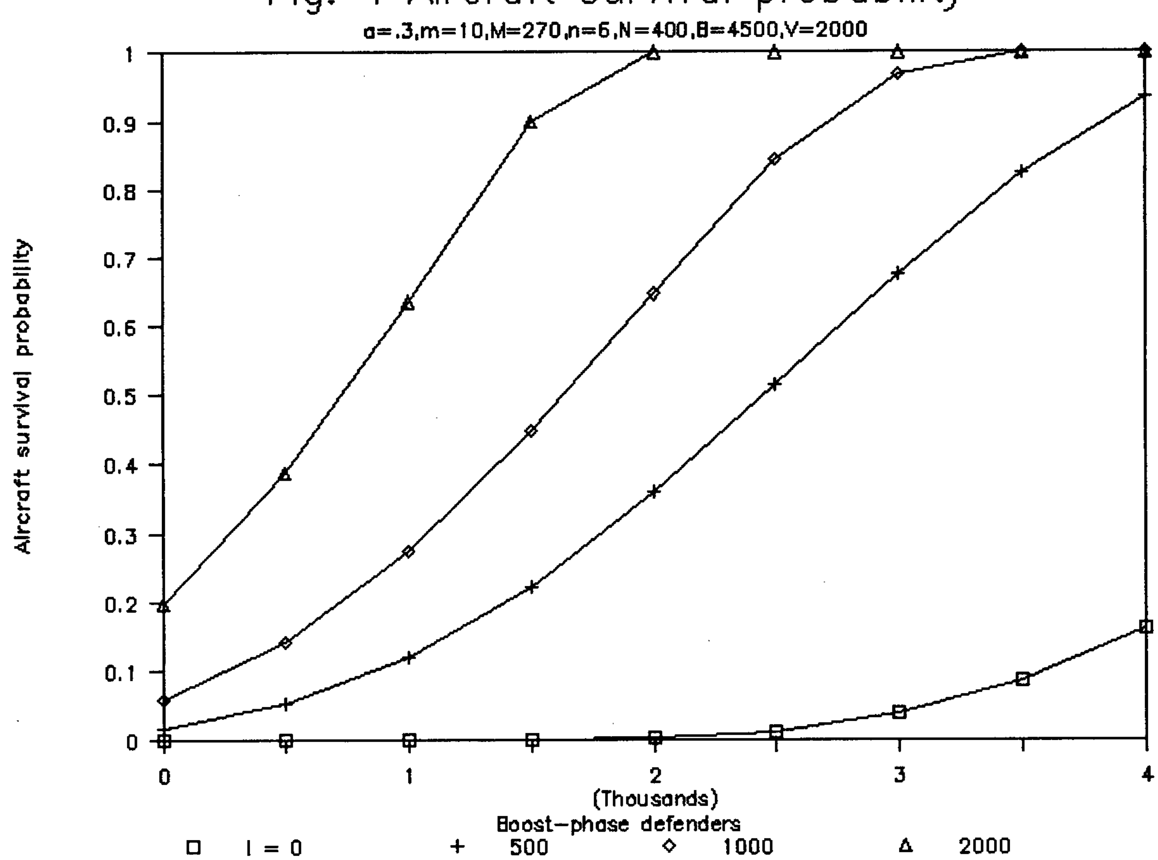


Fig. 5 Aircraft restrike on value

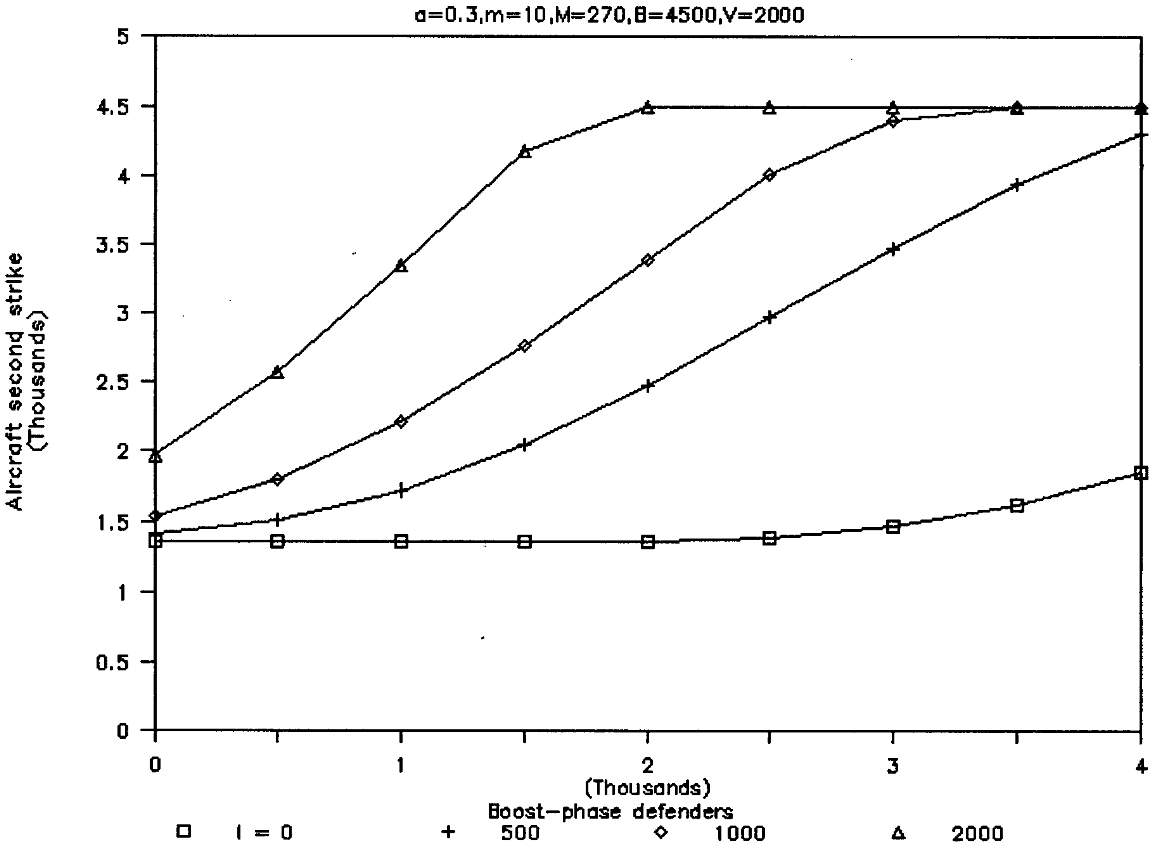
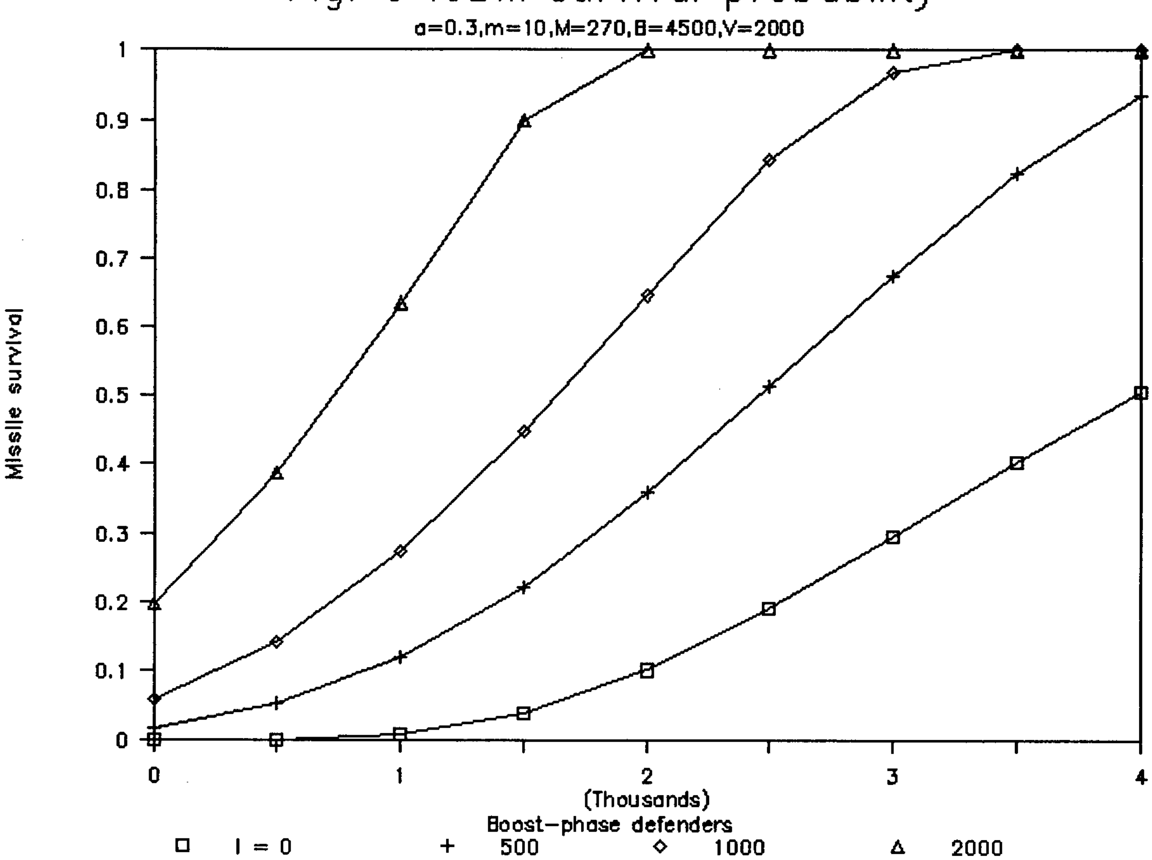


Fig. 6 ICBM survival probability



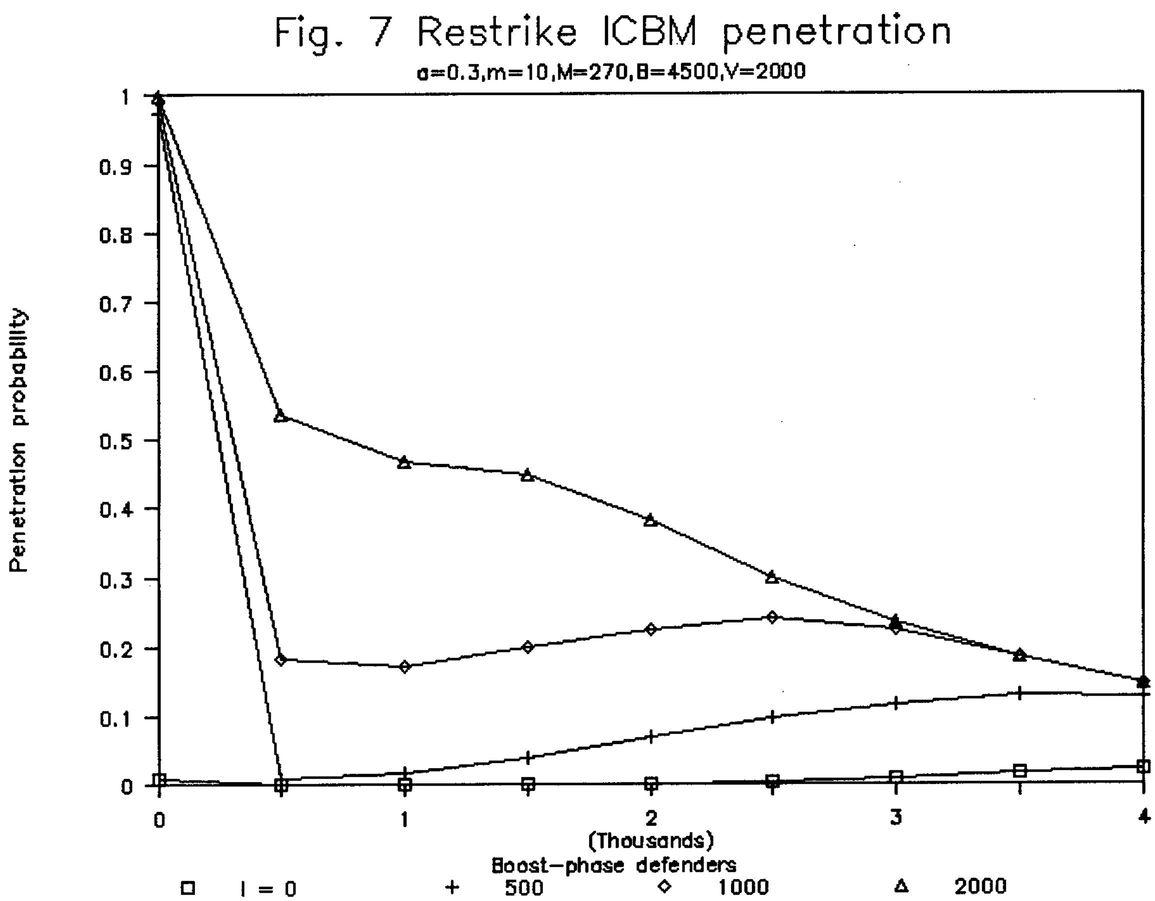


Fig. 7 Restrike ICBM penetration
a=0.3,m=10,M=270,B=4500,V=2000
Penetration probability
(Thousands)
Boost-phase defenders
I = 0
500
1000
2000

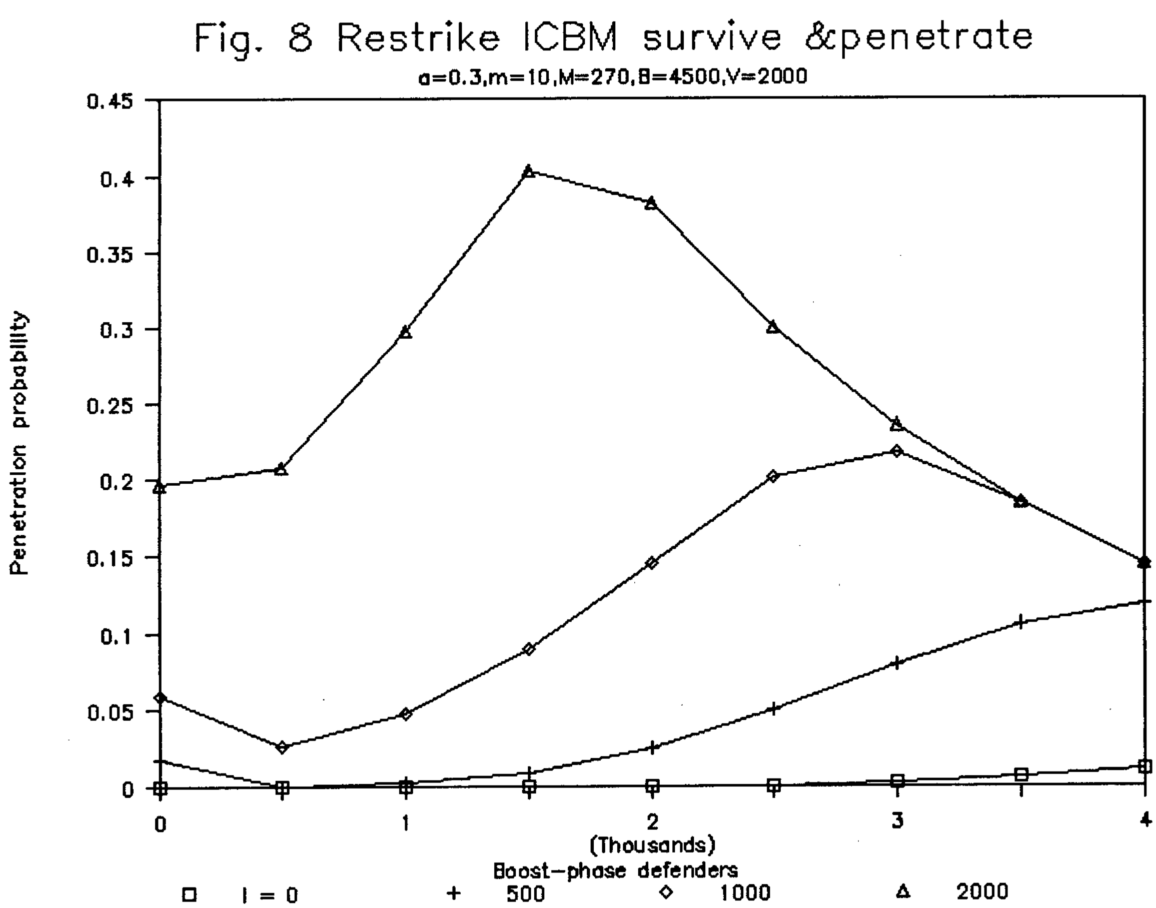


Fig. 8 Restrike ICBM survive &penetrate
a=0.3,m=10,M=270,B=4500,V=2000
Penetration probability
(Thousands)
Boost-phase defenders
I = 0
500
1000
2000

Fig. 9 Missile restrike on value

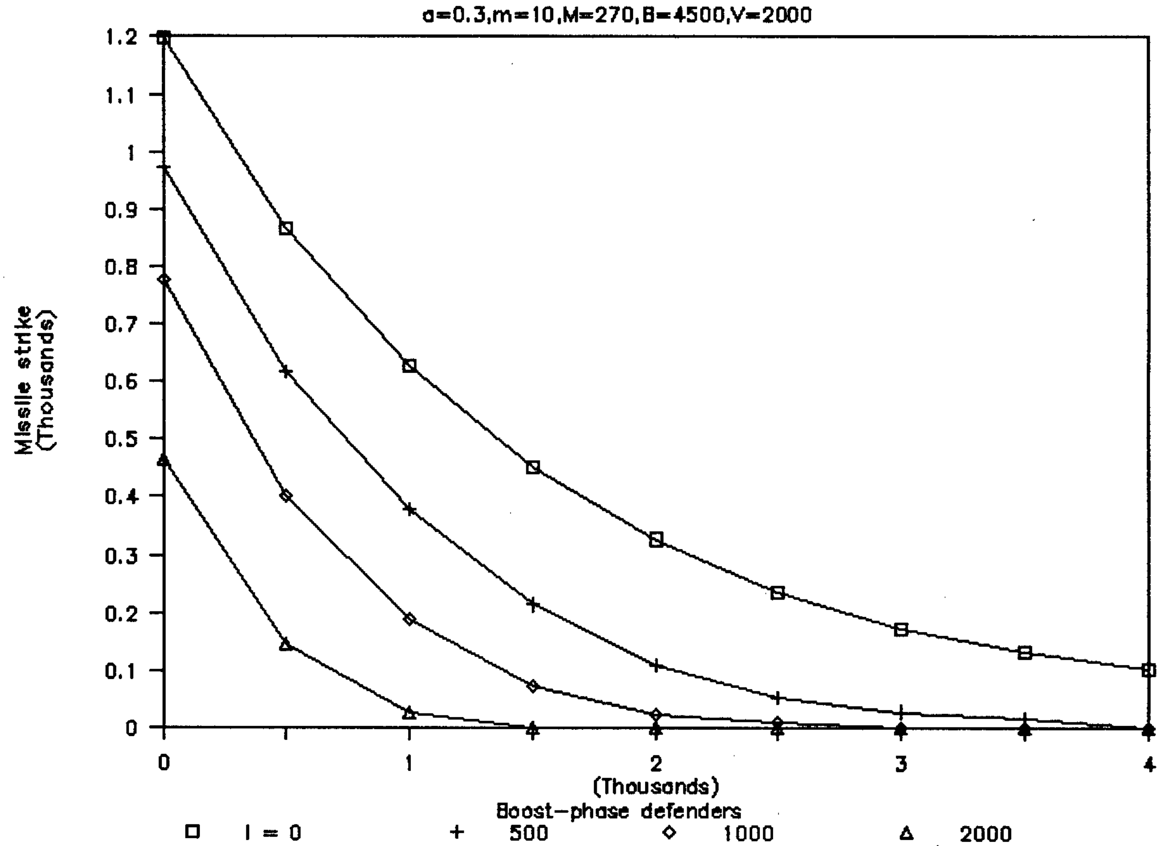
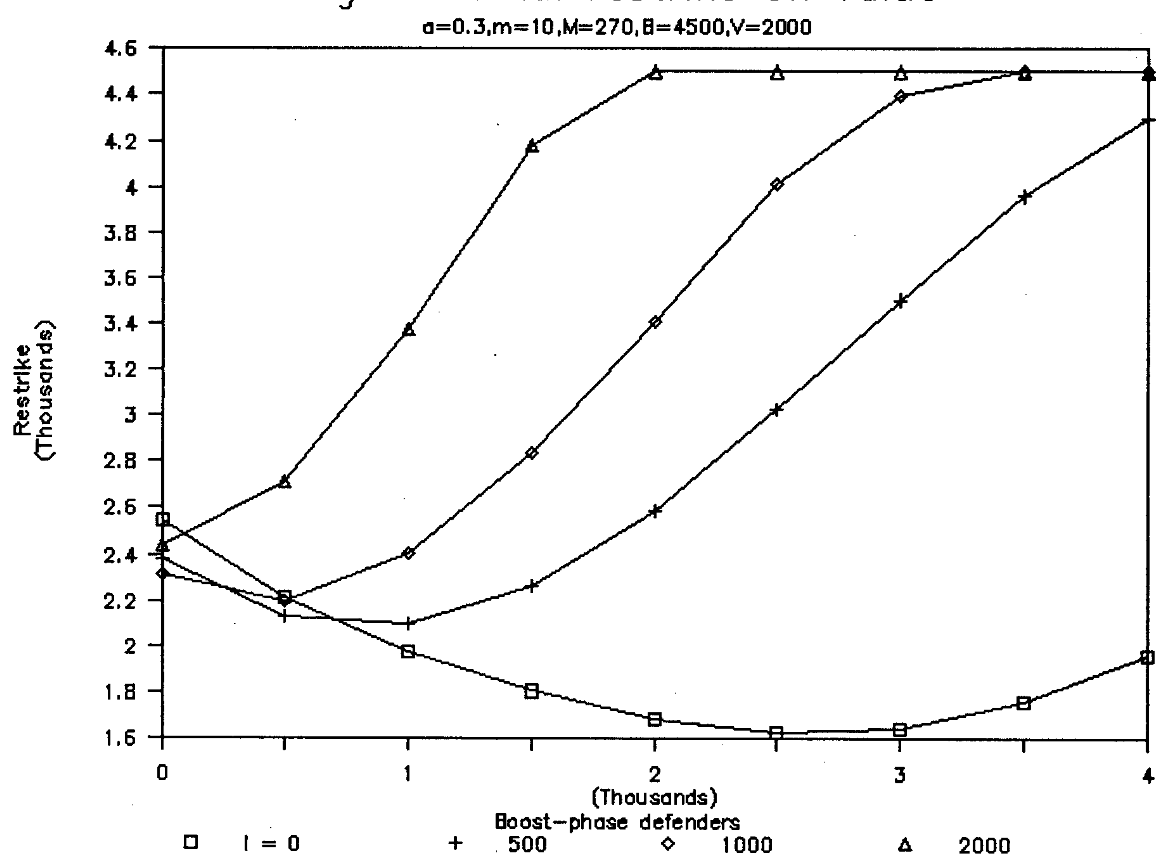


Fig. 10 Total restrike on value



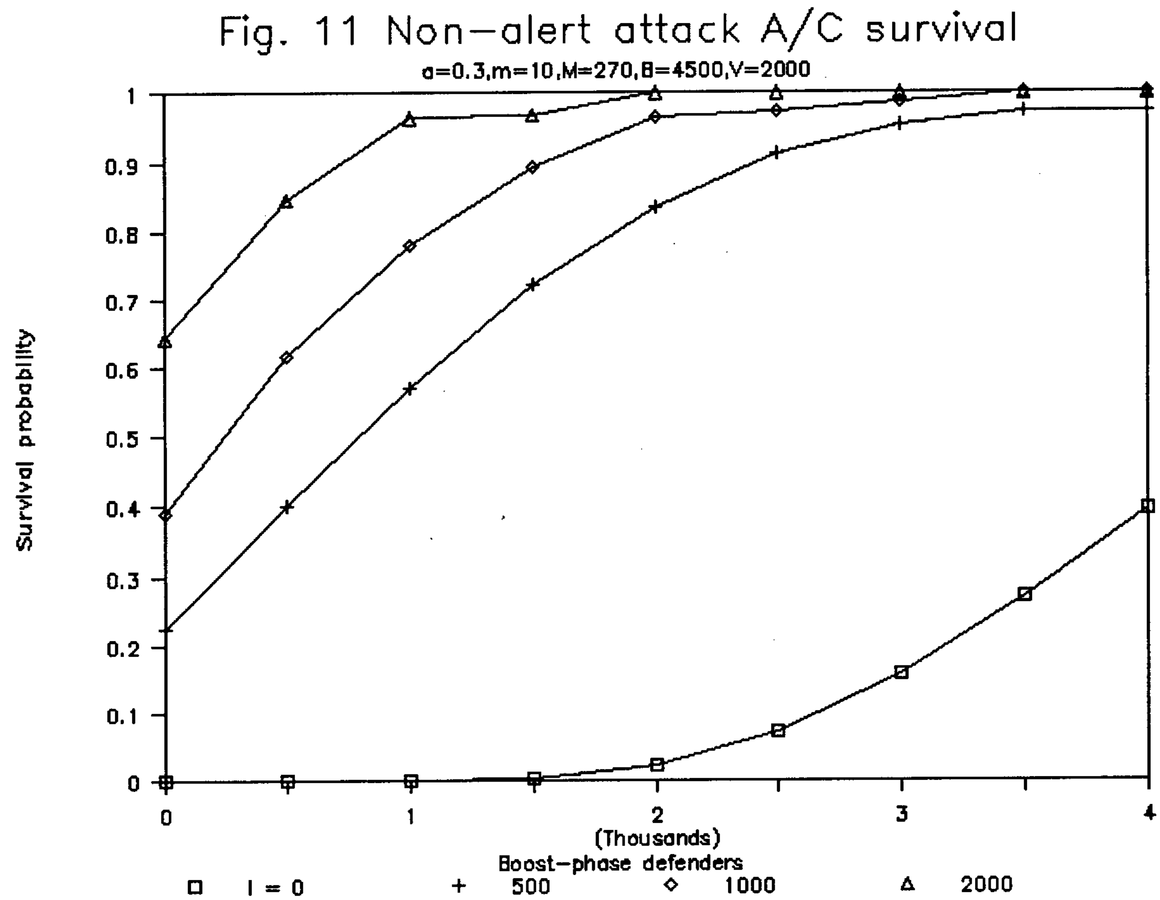


Fig. 11 Non-alert attack A/C survival
a=0.3,m=10,M=270,B=4500,V=2000
Survival probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
(Thousands)
Boost-phase defenders
I = 0
500
1000
2000

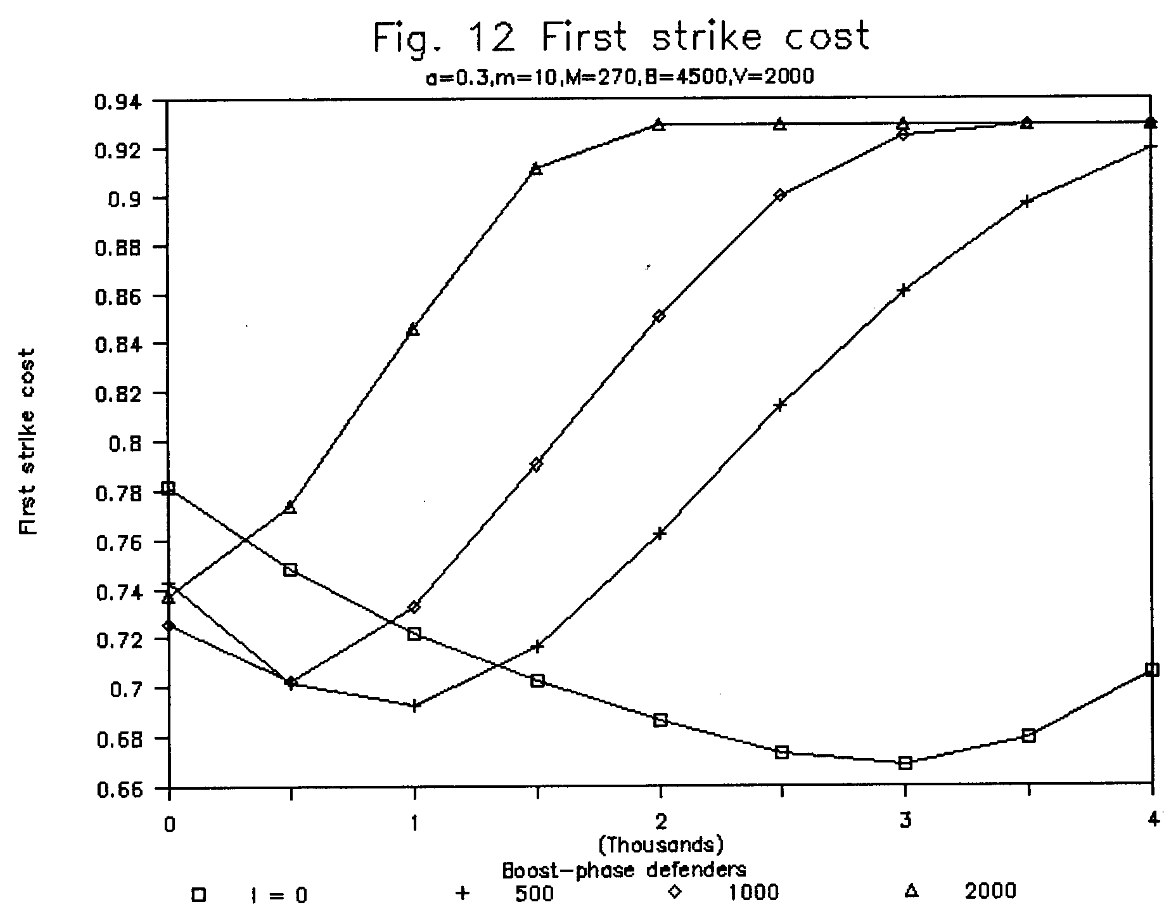


Fig. 12 First strike cost
a=0.3,m=10,M=270,B=4500,V=2000
First strike cost
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72
0.7
0.68
0.66
0
1
2
3
4
(Thousands)
Boost-phase defenders
I = 0
500
1000
2000

Fig. 13 Restrike cost

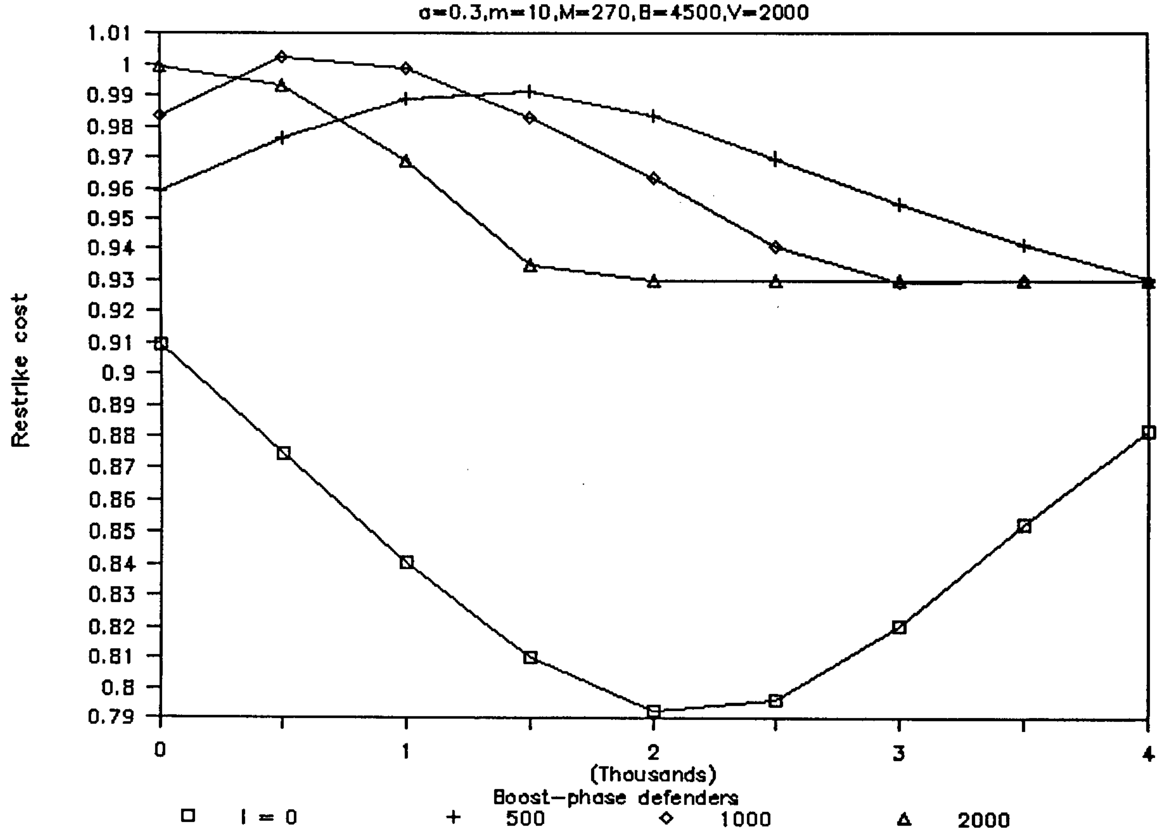


Fig. 14 Crisis stability index

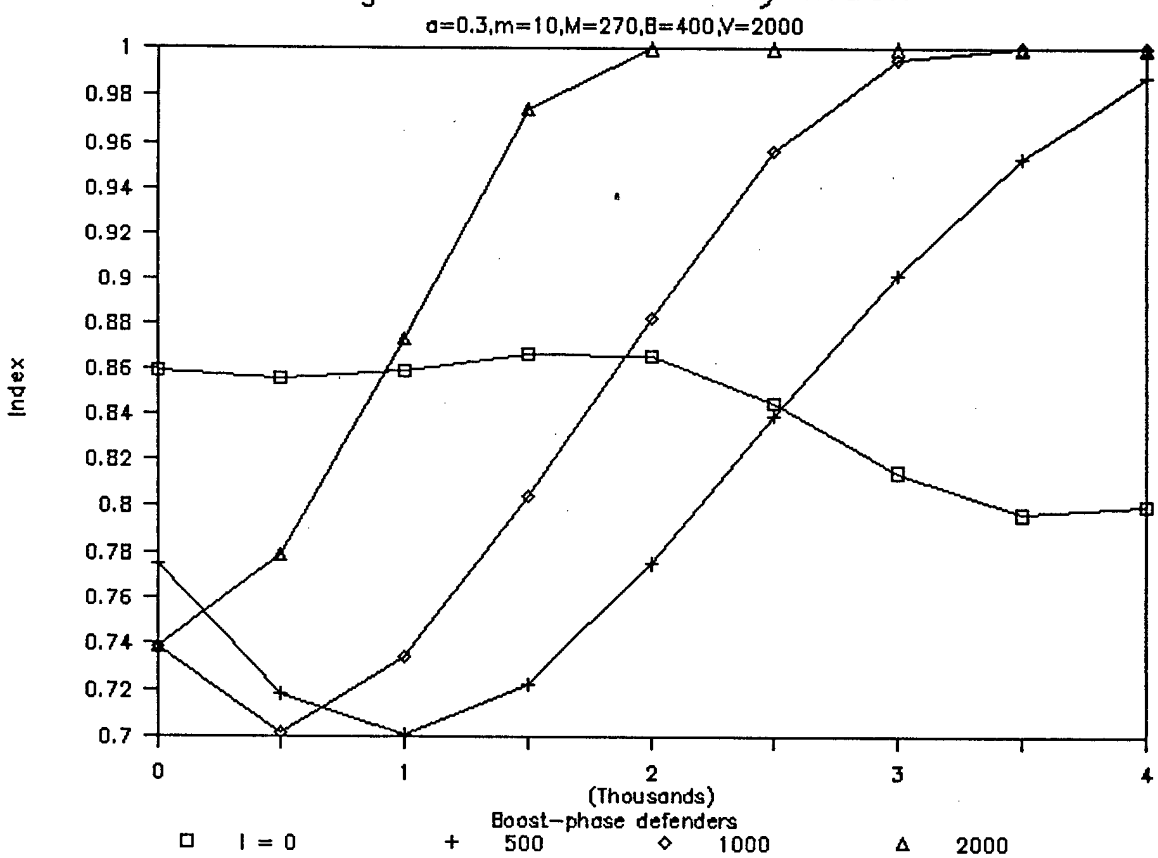


Fig. 15 Restrike sensitivity to attack

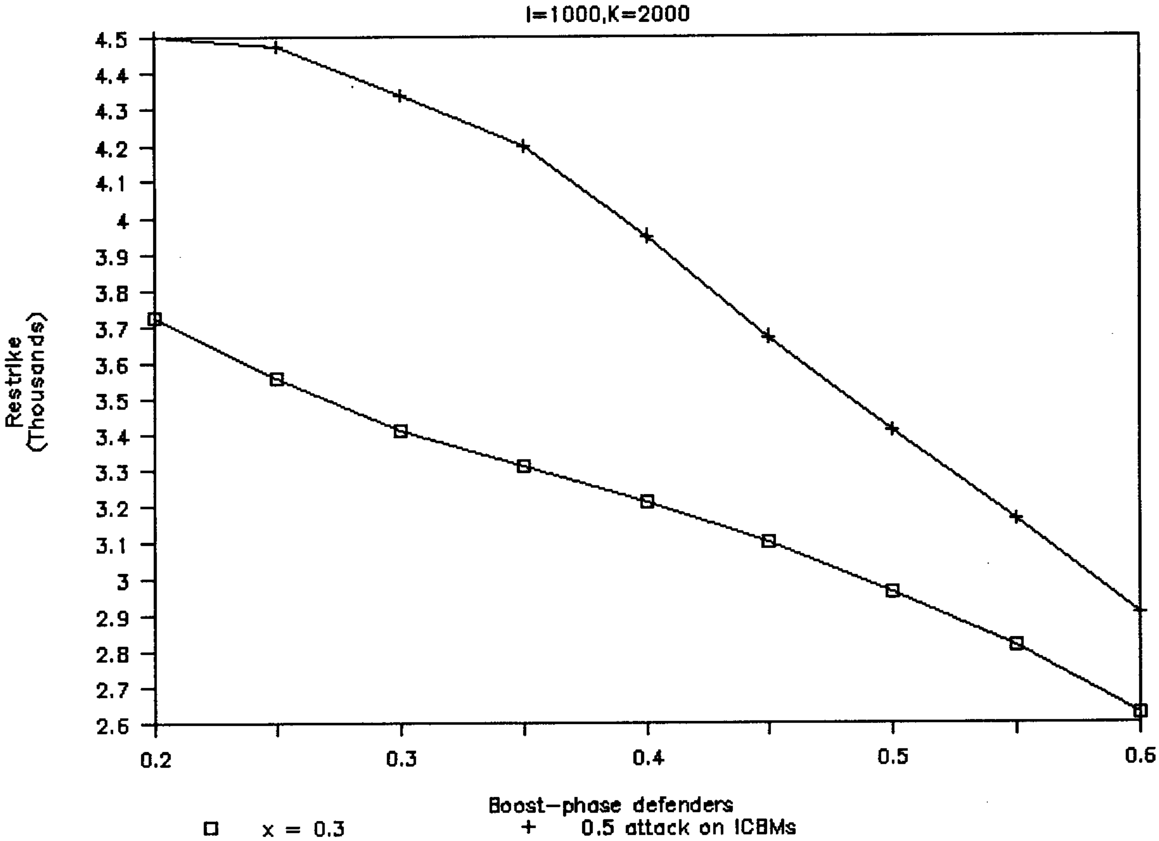


Fig. 16 A/C survival sensitivity to att

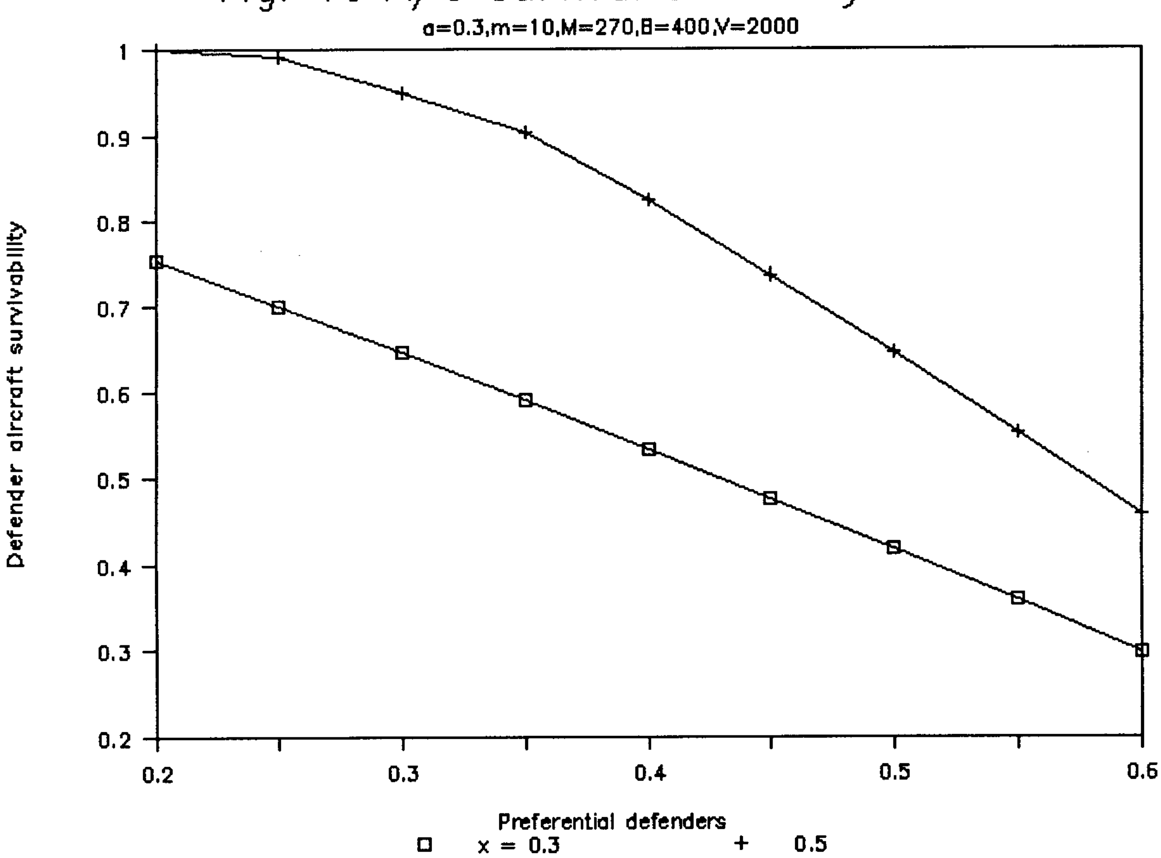


Fig. 17 Strike sensitivity non-alert AC

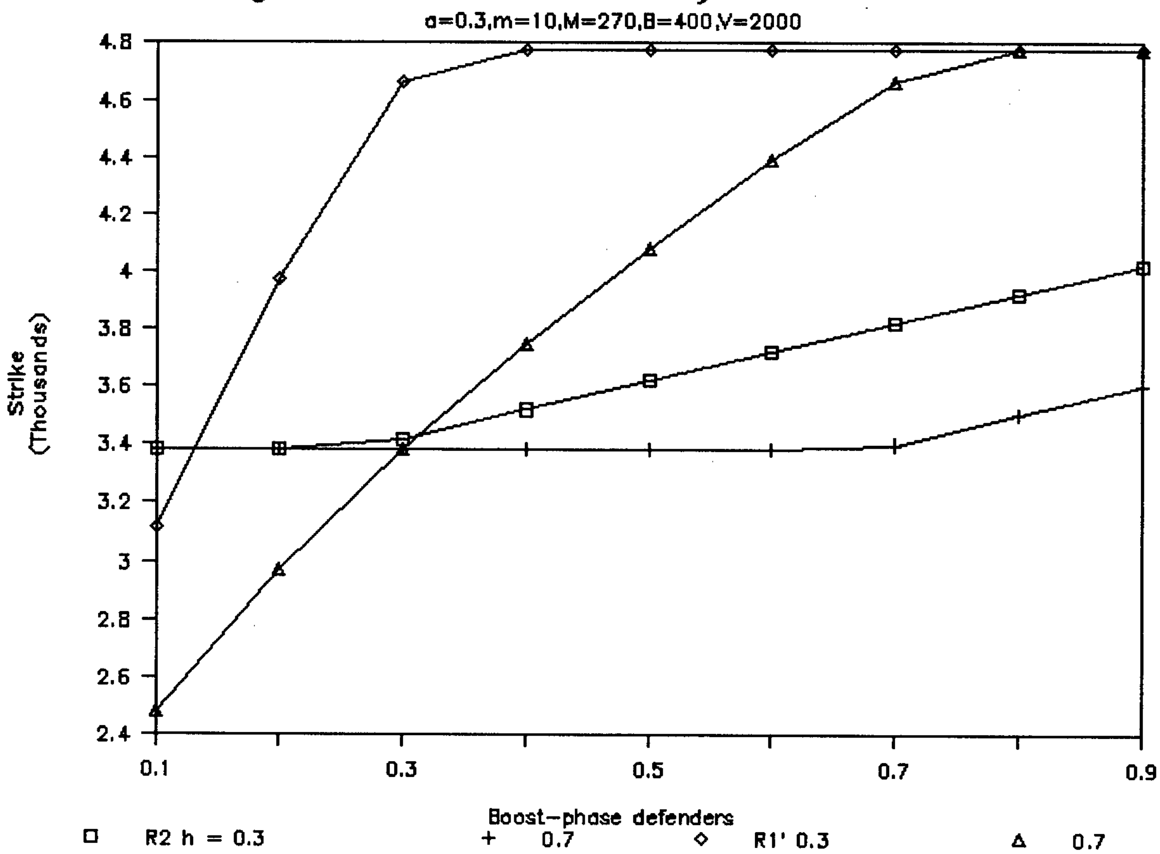


Fig. 18 Cost sensitivity to nonalert AC

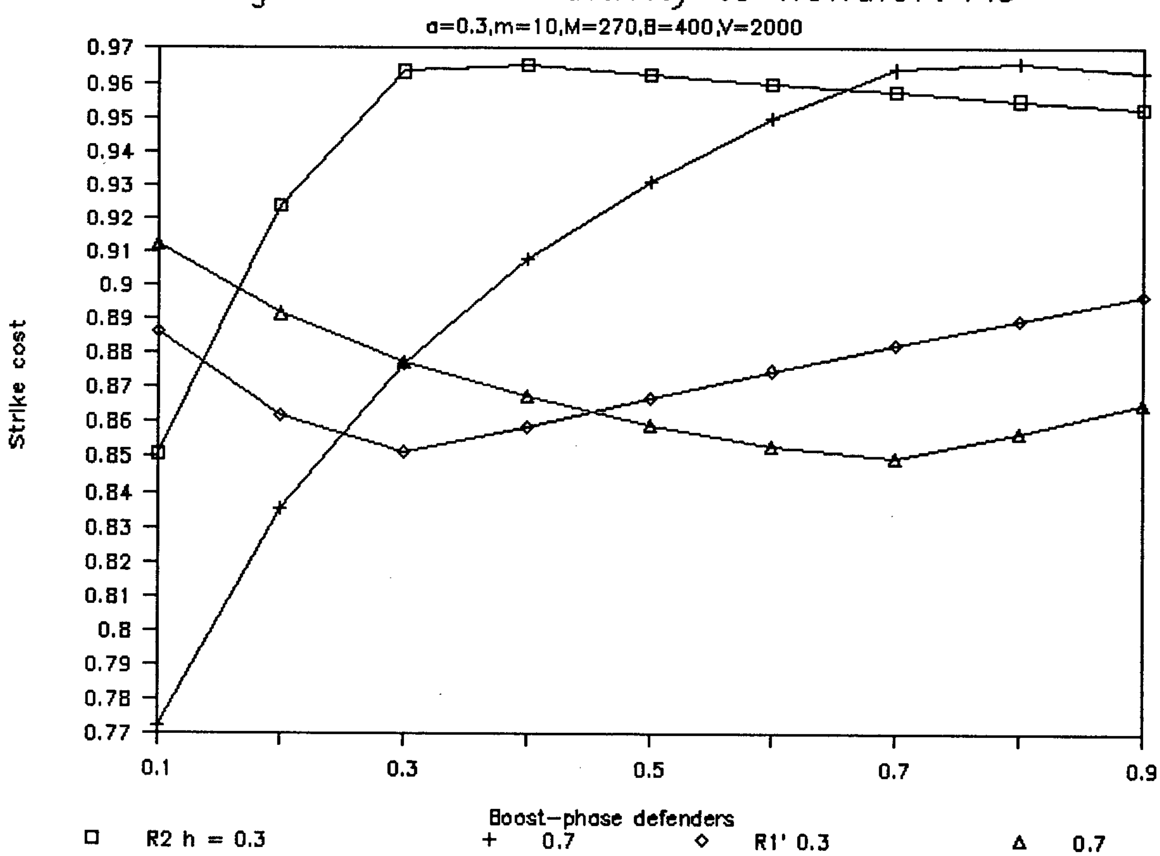


Fig. 19 Sensitiv index to nonalert A/C